

**Method for the production of structural components from fiber-reinforced thermoplastic material**

**DESCRIPTION**

Background

[Para 1] The invention is related to a method for the production of structural components from long fiber thermoplastic with integrated continuous fiber reinforcements as well as to an installation for the production of structural components of this kind. Known methods for the production of such structural components in most cases utilise plane continuous fiber reinforcements, e.g., in the form of semi-finished fabric products or with a sandwich structure, which, however, are very limited with respect to possible shaping and applications.

[Para 2] From international patent application publication WO99/52703 a method for the production of structural components is known, in the case of which molten continuous fiber strands are deposited on top of one another, so that they form a coherent load-bearing structure with plane joints and are pressed in a tool together with a forming mass reinforced with long fibers. Also these known processes, however, still manifest essential disadvantages with respect to efficient production, reproducibility and a defined development of an integrated continuous fiber load-bearing structure. In this manner it is not possible to produce a defined, single piece structural component, which can be made in a single press step and which comprises an integrated, precisely defined, optimally positioned and shaped, load-optimised continuous fiber reinforcing structure.

[Para 3] It would therefore be very desirable to overcome the disadvantages and limitations of the known production methods and to create a method for the efficient

automatic production of structural components, which overcomes the disadvantages and limitations applicable up until now and to produce single piece components capable of being pressed in a single step and with an integrated, precisely defined, optimally positioned and three-dimensionally shaped reinforcing structure, which corresponds to the loads and forces to be absorbed.

#### Summary of the invention

[Para 4] According to the invention, a method for the production of structural components is disclosed, and by an installation for the production of structural components. By means of the defined, short shock-cooling with CF (continuous fiber) – profile shaping and the formation of a dimensionally stable casing layer a precisely defined shape and positioning of CF – profiles in the LFT (long fiber thermoplastic) – mass as well as an optimum bonding at the interface is achieved.

[Para 5] Also disclosed are advantageous further developments of the invention with particular advantages with respect to efficient cost-effective series production capable of being automated, with short cycle times as well as optimum alignment and forming of the continuous fiber reinforcing structures with improved mechanical characteristics. With this, it is possible to produce light structural components for a large number of applications, e.g., for means of transportation, vehicles and vehicle components with load-bearing functions and this in a simple and precise manner.

#### Description of the drawing

[Para 6] The invention will be described with respect to a drawing in several figures.

What is shown is:

- o Fig. 1 – schematically the method according to the invention with profile shaping and defined shock-cooling,
- o Fig. 2 – temperature dependence in a CF – profile during the shock-cooling for different shock-cooling periods,
- o Fig. 3 – temperature dependence in a CF– profile during the shock-cooling for different tool temperatures and heat transfers,
- o Fig. 4 – an example with the shock-cooling differing zone by zone on a CF – profile,
- o Fig. 5a – the enthalpy as a function of the temperature during the heating-up and cooling-down of partially crystalline thermoplastics with a crystallisation hysteresis range,
- o Fig. 5b – the temperature control on the surface during the shock-cooling in the enthalpy diagram,
- o Fig. 5c – the temperature control in the lower layer during the shock-cooling in the enthalpy diagram,
- o Fig. 6 – the temperature distribution in the CF – profile following the shock-cooling,
- o Fig. 7 – the temperature distribution in the CF – profile and in the LFT – layer during the pressing in the LFT – tool,
- o Fig. 8a – an arrangement of several CF – profiles in a structural component with a three-dimensional intersection point,
- o Fig. 8b – the LFT – shaping of the structural component with integrated CF – profiles,
- o Fig. 8c – a two-stage profile forming process,
- o Fig. 9a, b – two different cross section shapes of a CF – profile at different places in a rib,
- o Fig. 10 – an inverse tempered CF – profile,
- o Fig. 11 – a CF – profile production line with a CF – profile – forming station,

- o Fig. 12 – an installation for the production of the structural components according to the invention with CF – profile forming station and LFT –press,
- o Fig. 13 – a positioning of CF – profiles on top and at the bottom in an LFT –pressing tool,
- o Fig. 14 – a structural component as a bumper beam support, and
- o Fig. 15 – a structural component as an assembly support (front end).

[Para 7] Where possible, like items among the various figures have been indicated with like reference designations.

#### Detailed description

[Para 8] Fig. 1 schematically illustrates the method according to the invention for the production of structural components out of long-fiber thermoplastic material (LFT) with integrated continuous fiber (CF) – reinforcements in a single stage LFT – pressing process by means of shock-cooling and CF – profile compression moulding in its sequence.

[Para 9] In a heating station 15 impregnated, particularly, pre-consolidated CF – tapes or bands 5 are completely melted to a practically homogeneous temperature  $T_{p0}$ , which is selected to be well above the melting point  $T_m$ , and subsequently transferred into a two-part profile tool 21 (here in 21u where “u” means “under”) of a CF – profile forming station 20. Here the CF – tapes 5 with an input temperature  $T_p$  are formed into a chosen CF – profile 10 by means of pressing for a short time during a precisely defined shock-cooling period  $t_s$ . During this form pressing and shock-cooling, a shock-cooled, dimensionally stable thin casing layer 12 is formed through the contact of the CF material with the thermally conditioned profile tool 21, namely, 21o (“over”) and 21u (“under”), with a defined, relatively low tool temperature  $T_{wp}$  and through a high heat transfer  $Q_1$  from the hot CF – profile into the profile tool 21. As will be discussed in more detail below, the tool

21 has an ability to conduct a lot of heat away from the CF material very quickly, and this is advantageous for later method steps.

[Para 10] After a defined shock-cooling – and pressing period  $t_s$ , the CF – profile 10 is immediately completely separated from the profile tool, transferred into an LFT – tool 31 (31o meaning “over”, 31u meaning “under”) of an LFT – press 30 and there positioned in a precisely defined manner in suitable shapings of the tool. Subsequently a molten LFT – mass 6 with a temperature  $T_f$ , which is situated above the melting point  $T_m$ , is introduced and put under pressure together with the CF – profile 10 and pressed, so that the casing layer 12 at the surface 11 of the CF – profiles is melted open again and is thermoplastically melted together with the introduced surrounding LFT – mass 6. In this way the newly introduced LFT material is able to form a very good bond with the outer layer of the CF material.

[Para 11] The structural components being combined in the previously mentioned step include at least one integrated, shock-cooled CF – profile. The temperature control during this process, i.e., the adjustment of the thermal and temporal parameters and of the shock-cooling period  $t_s$  takes place in correspondence with requirements which will presently be discussed, which are capable of being achieved with the method according to the invention:

- o a – At the contact points of the CF – profile with a gripper for the transfer into the LFT – press 30, a non-sticking, solid profile surface is formed.
- o b – The dimensional stability of the CF – profiles 10 during the transfer into the LFT – press has to be sufficient, so that the CF – profiles are capable of being positioned in the LFT – tool precisely in the required position and shape.
- o c – The shape preservation of the CF – profile during the pressing with the LFT –mass 6 in the LFT – press is adjusted in such a manner, that following the pressing the required final shape of the CF – profile results in the component doing what is needed in each

particular location. For example in some particular locations it will be desired that the CF-profile preserves its shape completely, while in other particular locations it will be desired that the CF – profile merges fully into the surrounding LFT –mass.

o d – The interface joint at the contact surfaces 9 between the CF – profile and the surrounding LFT – mass has to achieve the required strength.

[Para 12] As will be discussed below, the method can be carried out so as to develop a thinner or thicker solidified casing layer 12.

[Para 13] Experience shows that as a general matter, the greater the shock-cooling, the greater the preservation of the shape (characteristics a, b, c) while with a lesser shock-cooling the shape change during the pressing is enhanced and the interface bonding (characteristic d) is strengthened at the beginning.

[Para 14] An example with a high degree of shape preservation is shown in Fig. 9a with a CF –profile in a rib. On one side of the CF – profile (adjacent to the lower LFT – tool 31u) a stronger shock-cooling with a stronger casing layer is able to take place, while on the opposite side of the CF – profile nonetheless a good interface bonding with the introduced surrounding LFT – mass 6 is achieved by means of a medium shock-cooling with a normally formed casing layer (on the side of the upper LFT – tool 31o of Fig. 1).

[Para 15] In general a surface 11 of the CF – profiles adjacent to the LFT – tool 31 is able to be previously strongly shock-cooled on one side (because it will not later be required to be bonded to the LFT – mass) and simultaneously the opposite side is able to be shock-cooled less strongly for the optimum bonding with the LFT – mass (refer to Fig. 4).

[Para 16] The optimum temperature control corresponding to the respective requirements of the CF – profiles (10) is achieved by a corresponding adjustment of the process parameters. These are:

- o  $T_p$  – the input temperature of the CF – profile prior to the shock-cooling, after the heating up to a homogeneous temperature  $T_{p0}$  in the heating station 15.

[Para 17] During the shock-cooling:

- o  $t_s$  – the shock-cooling period, i.e., the duration of the pressing and with this of the heat transfer  $Q_1$
- o  $T_{wp}$  – the temperature of the profile tool 21
- o  $a_e$  – the heat penetration coefficient during the contact with the tool 21; this is determined by the choice of material and the characteristics of the tool: specific heat  $c$ , thermal conductivity  $\lambda$  and specific density  $\rho$ . This results in  $a_e = (\lambda \cdot \rho \cdot c)^{1/2}$ .
- o  $Q_1$  – the heat transfer from the CF – profile 10 to the tool 21 is therefore given by  $Q_1 = f(t_s, T_p - T_{wp}, a_e)$ .
- o  $T_a, T_i$  – temperatures on the surface 11 of the surface or inside of the CF – profile
- o  $t_t$  – transfer time up to the contact of the CF – profile with the LFT – mass in the LFT – press.

[Para 18] Heat transfer during the LFT – pressing:

- o  $T_f$  – temperature of the introduced LFT – mass 6 prior to the pressing
- o  $T_{wl}$  – temperature of the LFT – tool 31
- o  $Q_2$  – the heat transfer from the hot LFT – mass 6 to the CF – profile 10 here results as a function  $f(Q_1, T_a, T_i, T_f, T_{wl})$ .

[Para 19] During the adjustment of these parameters, also the thickness  $d_p$  of the CF – profiles and the materials characteristics are included. The thickness  $d_p$ , for example, may be between 2 and 5 mm.

[Para 20] Figs. 2, 3, 6, and 7 each portray a physical distribution of temperatures. In each figure, one or more graphed lines will each depict temperature as a function of position for a particular time. For example, in Fig. 2, there is a mass of material 10 between

two tool surfaces 11. The two surfaces to the left and right of Fig. 2 may, for example, be the surfaces 11 at the top and bottom of the center region 20 in Fig. 1. In Fig. 2, a top curve containing point  $T_p$  represents a temperature distribution as a function of position when the material 10 has first been introduced and before very much heat has been conducted away from the material 10. In Fig. 2, the next curve downwards contains a point  $T_{i2}$  and portrays a temperature distribution as a function of position after an amount of heat  $Q_{1.2}$  has been extracted from the mass of material 10. In this same figure, the next curve downwards contains a point  $T_{i1}$  and portrays a temperature distribution as a function of position after an amount of heat  $Q_{1.1}$  has been extracted from the mass of material 10.

[Para 21] Figs. 2, 3 schematically illustrate different settings of the shock-cooling parameters. They illustrate temperature dependences in a CF – profile  $T(d)$  over the layer thickness  $dp$  after a shock-cooling carried out at the time  $t = t_s$ .

[Para 22] Fig. 2 illustrates two temperature dependences  $T_1(d)$ ,  $T_2(d)$  for two different shock-cooling periods  $t_{s1}$ ,  $t_{s2}$ , with the same tool temperature  $T_{wp}$ . The longer shock-cooling period  $t_{s1}$  with a heat transfer  $Q_{1.1}$  results in a correspondingly stronger, thicker casing layer 12.1 (solidified below the melting temperature  $T_m$ ) and the shorter shock-cooling period  $t_{s2}$  with a lesser heat transfer  $Q_{1.2}$  results in a thinner casing layer 12.2.

[Para 23] Fig. 3 illustrates different temperature dependences  $T(d)$  with a constant shock-cooling period  $t_s$ , however, with different tool temperatures  $T_{wp1}$ ,  $T_{wp2}$ ,  $T_{wp3}$  with corresponding heat transfers  $Q$  and the resulting casing layers 12, wherein the intensity of the shock-cooling decreases from  $T_1$  to  $T_4$  (refer to Fig. 4):

- o  $T_1$ :  $T_{wp1}$  = strong shock-cooling  $Q_{1.1}$  and casing layer 12.1
- o  $T_2$ :  $T_{wp2}$  = medium shock-cooling  $Q_{1.2}$  and casing layer 12.2
- o  $T_3$ :  $T_{wp3}$  = weak shock-cooling  $Q_{1.3}$  and casing layer 12.3



- o T4: no contact with the tool (open points, recesses, Fig. 4),  $Q_{1.4} = 0$ , i.e., no thermal transfer.

[Para 24] In this, the surface temperatures  $T_a$  of the CF – profile correspond to the tool temperatures  $T_{wp}$  and the temperatures inside the profile  $T_i$  are situated in the vicinity of the input temperature  $T_p$  of the heated CF – tape. It is thought preferable to use short shock-cooling periods  $t_s$  and low tool temperatures.

[Para 25] The shock-cooling periods  $t_s$  are preferably between 1 and 5 sec., and are more preferably approximately 2 – 4 sec., although in special cases also longer times, e.g., of up to 10 sec. would be possible. The transfer times  $t_t$  in the LFT – press amount to, e.g., between 5 and 20 sec.

- o By means of the adjustment of the parameters, and by controlling temperatures, the shock-cooling is correspondingly adjusted to the respective requirements in order to:
  - o achieve the optimum dimensional stability for the handling of the CF – profiles and for the required final shape of the profile after the pressing operation and
  - o achieve an optimum bonding between the CF – profile and the LFT – mass (bond strength).

[Para 26] Differing requirements in certain zones, however, may be demanded of a CF – profile (with respect to the criteria a, b, c, d mentioned above), for example because of the intended function of the respective part or of the side or of the zone of a CF – profile. For example, with a CF – profile of Fig. 9a or in the case of a component of Fig. 8, it is necessary to take into account the intended zones of force transfers and force introductions.

[Para 27] It is a very important advantage of the shock-cooling and profile shaping according to the invention, that the shock-cooling on the EP – profiles is capable of being adjusted on a zone-by-zone basis differently and respectively for each zone. Fig. 4 shows

how this may be adjusted on a zone-by-zone basis. Fig. 4 schematically illustrates different zones with differing shock-cooling in each of the zones, with the zones distributed longitudinally on a CF – profile 10. In this example, each of zones Q1.1 to Q1.4 has its own amount of shock-cooling, in analogy to the example of Fig. 3. In doing so, these differing zones on the profile tool 21 may comprise differing temperatures Twp1, Twp2, Twp3 as well as also differing material characteristics ae1, ae2, ae3. As illustrated in Fig. 4, each side of the EP – profile (over and under) is also capable of being differently shock-cooled with the corresponding profile tool parts 21o und 21u. The desired extent of shock cooling for each zone on the tool 21 is capable of being achieved by thermal conditioning (heating, cooling) and the tool temperature Twp as well as by the material characteristics ae, i.e., metallic materials and possibly local insulating coatings.

[Para 28] It is instructive to discuss exemplary materials for use with the method according to the invention. The LFT – mass 6 preferably comprises an average fiber length of at least 3 mm. Even better mechanical properties are achieved with greater fiber lengths of, e.g., 5 – 15 mm. The continuous fiber reinforcement (CF) may consist of glass –, carbon – or aramide fibers, and for the highest compressive strength boron or steel fibers may be employed.

[Para 29] The CF – profiles may mainly be built-up of UD (unidirectional) – layers (0°) or continuous fiber strands of different kinds. It is also possible to use layers with differing fiber orientations, for example alternating layers of 0°/90° or 0°/+45°/-45° fiber orientations. The CF-profiles may also comprise a thin surface layer (e.g., 0.1 – 0.2 mm) made of pure thermoplastic material without any CF – fiber reinforcement.

[Para 30] The shock-cooling method according to the invention is particularly suitable for crystalline materials, because it is possible to exploit crystallisation characteristics of the materials. Especially suitable for structural components are crystalline, or more particularly

partially crystalline polymers as the matrix of the CF – profiles 10 and of the LF – mass 6, because such polymers are capable of achieving higher compressive strengths. It is also possible, however, to utilise amorphous polymers such as ABS or PC. The crystalline thermoplastic material may, for example, consist of polypropylene (PP), polyethylene–terephthalate (PET), polybutylene–terephthalate (PBT) or polyamide (PA). In the discussion that follows, the crystalline behavior and the shock–cooling are further explained on the assumption that polypropylene PP is employed.

[Para 31] To this end, Fig. 5a shows the enthalpy of polypropylene (PP) as a function  $En(T)$  of the temperature. Curve a shows the enthalpy of the PP during melting or heating–up. During melting, the temperature starts at a value that is lower than the melting point  $T_m$  (approximately 165° C). As may be seen from curve a, the enthalpy increases strongly as the temperature rises and moves toward the melting point  $T_m$  (or stated differently the slope of curve a is relatively high). The great increase in enthalpy (that is, the high slope of the curve) as a result of the melting of the crystalline zones. Stated differently, it takes quite a bit of added heat to melt the crystalline zones of the material. If we assume that the next temperature change is a slow cooling–down, then the material follows curve b, in which the polymer remains amorphyously molten down to a lower solidification temperature  $T_u$  of approx. 125° C. Only as the temperature continues to decline below  $T_u$  does enthalpy strongly decline. This range of temperatures is called the range of crystal growth  $DT_{kr}$ . In the case of PP this range is approximately 70 – 125°C, and the amount of crystal growth is shown by the curve  $kr$ ). Between curves a and b in the figure is a hysteresis area  $DE_n$ , which corresponds to the latent heat of the crystallisation.

[Para 32] Importantly, it can be appreciated from Fig. 5a what happens if a cooling–down is forced upon the PP so quickly that crystallization is unable to occur. The straight line c shows the path, downwards and to the left, corresponding to a shock–like rapid cooling–

down. When this happens the polymer, which was amorphous above the temperature  $T_u$ , remains amorphous also below the temperature  $T_u$ , yet it changes its state from liquid to solid. Such an amorphous solid can be heated up again in a way which follows the straight line c upwards and to the right. If we compare the amount of heat that needs to be added to bring about a particular temperature change (for example from below  $T_u$  to above  $T_m$ ) for this amorphous material as compared with crystalline material, it can be seen that less heat is needed to bring about this temperature change if the starting material is the amorphous material. The reason for this is of course that the amorphous material contains the latent energy  $\Delta H_u$ . This permits a very rapid heating-up corresponding to the straight line c.

[Para 33] In the method according to the invention can be carried out by means of the following process steps S1 – S4:

- o S1 – Shock-cooling ( $t_s$ )
- o S2 – Transfer into the LFT – press ( $t_t$ )
- o S3 – Initial heating-up again of the profile surface layer (11) during the LFT – pressing and
- o S4 – subsequent cooling-down during the LFT – pressing (S4.1) and after the pressing (S4.2).

[Para 34] These process steps are further explained in conjunction with the Figs. 5b, 5c, 6 and 7. Figs. 5b and 5c illustrate the temperature control on the surface 11 and in lower a layer 13 below surface 11. Figs. 6 and 7 illustrate the temperature dependence  $T(d)$  in the CF – profile 10, particularly in the CF – profile and in the LFT – mass 6 during pressing.

[Para 35] Fig. 5b illustrates a temperature control on the surface 11, and in particular in a surface layer  $T_a(11)$  during the shock-cooling in the enthalpy diagram, this in conjunction with Figs. 6 und 7. During the shock-cooling the surface 11 of the profile within the shock-

cooling period  $t_s$  is very rapidly lowered down to the temperature  $T_{a1}$  (step S1). Subsequently, during the transfer time  $t_t$  a temperature equalisation with a rapid rise again of the surface temperature to a temperature  $T_{a2}$  takes place (step S2), which is situated clearly below the melting point  $T_m$ . During the subsequent pressing with the liquid LFT – mass 6, the profile surface 11 is initially heated-up again to a temperature  $T_{a3}$  (step S3), which is situated above the melting point  $T_m$ , and in doing so is completely melted together with the LFT – mass. Subsequently in the step S4 a slow cooling-down takes place, initially still during the pressing (S4.1) and thereafter following the removal from the LFT – press (S4.2), wherein a further crystallisation takes place in the temperature range  $DT_{kr}$ . A sufficiently good interface bonding and melting together CF-LFT, however, is capable of being achieved also with a stronger shock-cooling with a lower surface temperature  $T_{a3}^*$  (after step S3), which is situated clearly above  $T_u$ , but slightly below  $T_m$ .

[Para 36] Fig. 5c illustrates the temperature control, and in particular the temperature curve  $T(13)$  in a lower layer 13 below the surface 11 of the CF – profiles (e.g., at a depth of 0.1 – 0.4 mm), in which a high crystallisation is produced by slow temperature control in the crystallisation temperature range  $DT_{kr}$  for an enhanced form stability. During the shock-cooling (S1) a strong crystallisation takes place in the lower layer 13. During the temperature equalisation (step S2) in the transfer time  $t_t$  and initially also during the pressing (S3), a heating-up takes place, wherein the temperature, however, is kept below the melting temperature  $T_m$ , in order that the crystallisation remains preserved. These temperature changes in the layer lower 13 take place more slowly than on the surface (Fig. 5b).

[Para 37] During the cooling-down (S4) a further crystallisation takes place. The transfer, positioning and pressing are carried out in such a way as to give rise to a stronger or

weaker formation of this crystallised zone in the layer lower 13, thereby providing a desired degree of dimensional stability.

[Para 38] Fig. 6 illustrates the temperature gradient  $T1(d)$  with a surface temperature  $Ta1$  in the CF – profile 10 following the shock-cooling at the point in time  $t = ts$  (step S1). Following the transfer into the LFT – press (step S2), rapidly a balanced temperature distribution  $T2(d)$  with a reached surface temperature  $Ta2$  is achieved after a transfer time  $t = tt$ . The crystallisation temperature range  $DTkr$  (approx.  $70 - 125^{\circ}C$ ), in which the crystal growth takes place ( $kr$  in Fig. 5a), is also indicated.

[Para 39] Fig. 7 illustrates the temperature gradient in the CF – profile 10 and in the adjacent LFT – layer 6 (with a thickness  $df$ ) during the pressing operation in the LFT – press. With the pressing, first the quantity of heat  $Q2$  is transferred from the hot LFT – layer 6 with a temperature  $Tf$  to the CF – profile 10 (step S3). In doing so, a temperature distribution  $T3(d)$  is produced, wherein the temperature  $Ta3$  on the profile surface 11 and at the interface 9 rapidly increases strongly and with this a high-quality melting together is achieved, together with a high bonding strength. Subsequently the temperature  $T4(d)$  in step S4 drops once again in correspondence with the LFT – tool temperature  $Twl$ . During the pressing together of CF – profiles 10 with the LFT – mass 6 and the subsequent cooling-down initially in the LFT – tool (S4.1) and then following the removal (S4.2), the temperature control can be selected in such a manner that the crystalline proportion (at the required position) is increased by means of a correspondingly slower transition through the crystal growth temperature range  $DTkr$ .

[Para 40] In analogy to the differing thermal conditioning by zone in the profile tool 21, the LFT – tool 31 may also comprise differing thermal conditionings, that is to say differing heat transfers by zone, by means of differing parameters: tool temperatures  $Twl$  and heat penetration coefficients  $ae$  in different zones of the LFT – tool.

[Para 41] Following the removal from the LFT – tool and after the cooling–down of the structural components, it is possible that slight shape changes occur, as a result of differing expansion coefficients of CF – profiles and LFT – mass and also of material contraction. These shape changes can be influenced and indeed can be compensated for, by means of a different temperature control during cooling–down in some places, by analogous thermal secondary treatment, or also by a corresponding shaping of the tools, which compensates the shape change (typically by pre–forming in the opposite direction).

[Para 42] In the case of partially crystalline polymers such as PP it is possible to select the temperature control in such a manner that the crystallisation characteristics are exploited for the improvement of non–deformability and bonding strength. For example:

- o in casing layer 12, and in particular in the layer lower 13, it is possible to increase the strength of the casing zone in the crystallisation temperature range DT<sub>kr</sub>;
- o on the profile surface 11 a minimum crystal growth can be achieved, if the surface temperature T<sub>a</sub> in step S1 and step S2 is very rapidly brought through the crystal growth temperature range DT<sub>kr</sub> and the profile surface during the pressing is rapidly and as completely as possible melted open and bonded with the LFT – mass (by Q2);
- o the shape stability is increased by a greater crystalline proportion in the casing layer, particularly in the lower layer 13; and
- o depending on the required further shapability during the LFT – pressing, a smaller or greater crystalline proportion is produced in the casing layer, particularly in the lower layer 13.

[Para 43] A temperature gradient at the interface 9 at the contact surface CF–LFT is capable of further increasing the strength of the joint CF–LFT by means of a directed crystal growth over the interface.

[Para 44] Figs. 8a, 8b, 8c illustrate possible shapings of the CF – profiles in correspondence with the differing functions and requirements at different points of a certain CF – profile, for example for use in a structural component so as to absorb external loads. For this purpose, the CF – profiles may comprise a three-dimensional profile shaping, which is integrated into the structural component in a precisely defined position. They may comprise bends, twists or folds in longitudinal direction and they may comprise special shapings 22 for force transfers to the LFT – mass and for the direct absorption of external loads, particularly for the receiving of inserts 4 (mounting parts), at which external loads are introduced into the component. The shaping of the surrounding LFT – mass 6 is also selected to match the shaping of the CF – profiles 10. Shapings of force transfer points (of forces and moments) inside a component (e.g., of a CF – profile through the LFT – mass on to other CF – profiles) are able to be formed both as shapings 22 of the CF – profiles as well as shapings 32 of the LFT – mass.

[Para 45] To maximize strength and rigidity, it is desirable to avoid abrupt transitions between the CF – profiles and the LFT – mass and instead to employ continuous transitions therebetween.

[Para 46] The three-dimensional shaping of the CF – profiles is implemented, for example, by a pre-forming of the molten CF – tapes 5 in the horizontal plane by the tape gripper 18 and by pre-forming elements 19 during the transfer into the CF – profile forming station 20 (refer to Fig. 11). In doing so, the CF – tapes 5 may also be twisted. Subsequently the shaping also takes place in the third dimension (vertically) by the profile tool 21, so that to a great extent any required three-dimensionally shaped CF – profiles can be produced.

[Para 47] Figs. 8a, b illustrate the example of a complex structural component in the form of a 2/3 rear seat back 74 with a central seat belt connection 60 for the middle seat of



a vehicle with several demanding load introductions for different load cases (crash loads). Fig. 8a in plan projection illustrates the arrangement of the CF – profiles in the component and Fig. 8b in a perspective view the LFT – mass 6 and drawn in it the integrated CF – profiles 10.1 to 10.4. This example illustrates the load-optimised shaping of the CF – profiles themselves as well as the load-optimised arrangement in a precisely defined position in the component to form a structure with a corresponding shaping of the LFT – mass 6 and with an optimum bonding strength between the CF – profiles carrying the main loads (with directed continuous fibers) and the complementing LFT – mass (with undirected long fibers).

[Para 48] Here four main load carrying points L1 to L4 result from:

- o the loads L1, L2 on the axle holders 59a, 59b, around which the rear seat back is able to be swivelled,
- o the load L3 on the lock 58, for fixing the rear seat back in its normal position and
- o the load L4 on the belt lock, resp., belt roller 60 for the central belt of the middle seat.

[Para 49] With this structural component the following load cases (with the further loads L5 to L9) are covered:

- o Front – and rear collision
- o Securing of any goods loaded
- o Belt anchoring
- o Head support anchoring.

[Para 50] For the receiving and transferring of all loads and forces the intersecting CF – profiles together with the joining force-transmitting shapings of the LFT – mass form a spatial, three-dimensional intersection structure 50. Here the CF – profiles respectively in pairs in the LFT – shapings form a moment-transmitting girder subject to bending:

- o The CF – profiles 10.1 and 10.4 in a crimp 7 of the LFT – mass form a girder subject to bending between the loads L1 and L4
- o and the CF – profiles 10.2 and 10.3 in the ribs 8 of the LFT – mass a girder subject to bending between the loads L2 and L3.

[Para 51] Through the three-dimensional intersection point 50, in this the load L4 on the belt roller and also in part other loads, which act on the girder subject to bending 10.1 / 10.4, is also supported on the other girder subject to bending 10.2/ 10.3 (and vice-versa).

[Para 52] The main forces, resp., loads L1 to L4 are received by means of force introduction points:

- o through shapings 22 and 32 of the CF – profile ends and of the LFT – mass for receiving the external forces with or without inserts 4.
- o In doing so, the inserts 4 prior to the pressing operation are able to be inserted into the LFT – tool and then pressed together with the CF – profiles and the LFT mass
- o or else it is also possible to fit them into the component later on.

[Para 53] Here the CF – profile 10.1 comprises an arc-shaped widening 22.1 for receiving an insert 4 at the axle bearing 59a. The other axle holder receptacle 59b is formed by shapings 22.2 of the CF – profiles 10.2 and 10.3 and by adapted joining shapings 32.2 of the LFT– mass. These profile ends 22.2 are bent over and in this manner anchored in the LFT – mass for the purpose of increasing the tensile strength. The lock 58 is bolted on to a lock plate on the CF – profile 10.3 and supported by the CF – profile 10.2. The belt roller 60 is supported by shapings 22 of the CF – profiles 10.1 and 10.4 and by LFT – shapings 32.

[Para 54] The smaller loads L8, L9 of head supports 61 here are absorbed through LFT – shapings 32. For reinforcement, however, it would also be possible to integrate an additional CF – profile 10.5 deposited transversely (in some zones oriented flat or vertically).

[Para 55] In this example the three-dimensional profile shaping is evident in many variants.

[Para 56] The depositing sequence of the CF – profiles into the LFT – tool is:

[Para 57] first the CF – profile 10.1, thereupon the CF – profiles 10.2 and 10.3 and subsequently the CF – profile 10.4. Then the liquid LFT – mass 6 is introduced and the complete component pressed in a single step as a single piece and as a single shell. In order to obtain as short as possible transfer times  $t_t$ , several or all CF – profiles (10.1 – 10.4) are able to be gripped with a multiple gripper 26 or robot, pre-positioned correctly relative to one another during the transfer and be inserted into the LFT – tool 31 together in a single step.

[Para 58] During the form pressing of the CF – profiles it is also possible to press several profiles in one profile tool 21 with a profile forming station, e.g., here the CF – profiles 10.2 and 10.3.

[Para 59] The profile shaping in the CF – profile forming station 20 in case of particularly complicated shapes may also be carried out by means of a multipart profile tool in a multi-stage shaping process. An example for this is illustrated in Fig. 8c with a three-part tool 21u, 21o and 21.3. In a two-stage shaping process, here first the tool parts 21o and 21u are closed and thereupon immediately on the side the tool part 21.3. In this manner it is possible to shape a  $90^\circ$  or  $180^\circ$  – arc – e.g., for zones, where forces are to be introduced.

[Para 60] Figs. 9a, 9b illustrate an example of a CF – profile 10, which over its length comprises differing cross-sectional shapes, this in adaptation to the forces to be transmitted and for the optimum bonding with the LFT – mass 6. The Figures in cross-sectional view illustrate a CF – profile 10a, 10b in a rib 8, e.g., corresponding to the profiles 10.2 or 10.3 of Fig. 8, at two different locations.

[Para 61] Fig. 9a illustrates a shaping 10a with a positioning shoulder 55 for fixing and holding the CF – profile in the required position – this especially during pressing, when the liquid LFT – mass is pressed into the rib. On top and underneath the CF – profile respectively comprises a thicker zone 56 as tensile – and compressive zones (in longitudinal fiber direction) for the transmission of moments. Located in between is a thinner thrust zone 57 with a correspondingly thicker adjacent LFT – layer 6 and with a large bonding surface area and a particularly strong interface joint.

[Para 62] With this, the shear resistance is increased by the adjacent LFT – layer 6 with isotropic fiber distribution (while the strength transverse to the fiber orientation in the CF – profiles 10 here is lower).

[Para 63] At another location according to Fig. 9b the profile cross-section 10b is changed corresponding to the force situation there: stretched, i.e., higher and narrower and without a positioning shoulder.

[Para 64] For the secure and accurate positioning and fixing of the CF – profiles, during the pressing with the LFT – mass, further positioning points 54 may be developed on the CF – profiles, which correspond to the shaping of the LFT – tool 31o (top) and 31u (bottom). Here the positioning point 54 serves for the accurate positioning below in the rib 8. Positioning points can also be arranged suitably distributed in the longitudinal direction of the CF – profiles.

[Para 65] In an analogous manner, profile shapes of this kind may also be positioned and fixed on crimped walls instead of in ribs 8.

[Para 66] Instead of the examples 8a, 9a, it is also possible to design the cross-sections of CF – profiles as “L”- or “Z”-shaped, depending on the application.

[Para 67] In addition to the shock-cooled CF – profiles, further shaped CF – profiles, which, however, have been treated separately and in a thermally inverse manner (i.e., solid

inside, liquid outside), may be brought into the LFT – tool for the non-deformable transfer and pressed together with the shock-cooled CF – profiles in a single step. As an example, the CF – profile 10\* according to Fig. 10 as a result of external heating-up is capable of comprising a molten external zone 89 and a still non-deformable cooler internal zone 88. For the handling and transfer, this CF – profile 10\* may be gripped by means of cold grippers at non-sticking contact points (which are thereby cooled) for a short period.

[Para 68] Figs. 11 and 12 illustrate examples of a CF – profile production line, and in particular of an installation for the implementation of the method according to the invention. Fig. 11 depicts an example of a CF – profile production line with a CF – profile forming station 20, with a semi-finished products store 14, a heating station 15, with a protection gas atmosphere 27 (e.g., with N<sub>2</sub>, for critical materials and temperatures), with a conveyor belt or a chain conveyor 16 (e.g., a studded chain with a non-sticking coating and a brush cleaning system), a band gripper 18 with pre-forming elements 19, which are attached to the upper CF – profile tool 21o, a CF – profile forming station 20 with shock-cooling, with a transfer portal 17 for the upper tool part 21o and with a CF – profile press 23. With a profile gripper 26 and a transfer robot, particularly a handling unit 42, the produced CF – profiles are transferred into the tool 31 of an LFT – press 30 and accurately positioned. From the semi-finished products store 14, the CF – tapes 5 having been cut to a suitable size (also with varying length, width and thickness) are brought to the heating station 15 with the chain conveyor 16 and there, e.g., with IR – radiators are completely melted open and heated-up to a homogeneous required tape temperature  $T_{p0}$ .

Subsequently the molten CF – tapes 5 are gripped with a band gripper 18 with pre-forming elements 19, which are attached to the upper tool part 21o, and during the transfer into the CF – profile forming station 20 are pre-formed (pre-formed in the horizontal plane, e.g., by means of positioning pins with bending or rotation of the molten tape), moved over the

lower profile forming tool 21u with the transfer portal 17, deposited there in the required pre-formed position and immediately pressed in the precisely defined, adjustable shock-cooling period  $t_s$  for the formation of the dimensionally stable casing layer 12. By means of the deformation in the profile tool, the required, defined three-dimensional shape of the CF – profile is obtained. Subsequently the CF – profiles 10 are immediately removed from the mould and with the profile gripper 26 transferred into the LFT – tool 31 of the LFT – press 30 by the robot 42 and accurately positioned. With the profile gripper 26 the CF – profiles 10 during the transfer are aligned to the required set-point position in the air, i.e., with respect to translation motion, rotation and inclination into the defined position for each individual CF – profile. With a profile gripper 26, such as a robot, the profiles are able to be individually gripped and transferred or else also several profiles gripped at the same time and simultaneously respectively aligned to the correct position and then deposited together.

[Para 69] In the example of Fig. 8, first the profile 10.1 is positioned, and thereupon together the CF – profiles 10.2 and 10.3 are each respectively vertically positioned in a rib and then the CF – profile 10.4 is positioned in a crimp, wherein also these four profiles are capable of being simultaneously transferred and positioned with a multiple profile gripper 26.

[Para 70] In order to avoid the molten CF – tapes 5 remaining stuck to the band gripper 18 and to the pre-forming elements 19, the tapes are able to be unstuck by means of a brief contact with cold gripper surfaces, which do not stick. A double-gripper of this type 18a, 18b comprises, e.g., two insulating small gripper contacts 18a and two stronger, cold, non-sticking gripper contacts 18b.

[Para 71] In a CF – profile forming station 20, with more than one profile tool 21.1, 21.2 it is also possible to simultaneously press several CF – profiles 10.

[Para 72] Fig. 12 illustrates a complete installation 40 with several CF – profile production lines with CF – profile forming stations 20.1, 20.2, 20.3 as well as with an LFT – processing facility 34, e.g., an extruder, and with an LFT – gripper 37 for transferring the molten LFT – mass 6 with the required temperature into the LFT – press 30, for example into the LFT – tool 31. The installation comprises partial control systems for the individual sub-assembly groups: a control 25 of the CF – profile forming stations, a control 35 of the LFT – processing facility and an LFT – press control 36, which can be combined in the installation control system 45 including the control system for the transfer robot 42.

[Para 73] Fig. 13 illustrates the accurately defined positioning of several CF – profiles (10.1 – 10.4) in an LFT – tool in differing fitting positions and with any needed inclinations between flat and vertical. In this, the individual CF – profiles can be positioned on the lower tool 31u and/or also on the upper tool 31o and also be fixed with suitable fixing elements 38. With the LFT – mass 6 introduced in between therefore correspondingly also components with elaborate CF – profile reinforcement structures can be produced in a single step.

[Para 74] The LFT – mass 6 may also be introduced and pressed with other analogous compressive manufacturing processes instead of extruding. Thus it is also possible to utilise LFT – injection processes with horizontal pressing and a vertical LFT – tool. Applicable as particularly suitable is also an injection moulding process with back pressing in the source flow with a moving tool with submerged edges, where the tool during the injection is first slowly opened and then pressed together. It is also possible, however, to implement a horizontal pressing with a vertical LFT – tool. Vertical injection with a horizontal LFT – tool is also possible.

[Para 75] Structural components according to the invention contain one or more shock-cooled CF – profiles 10, which comprise a precisely defined shaping and a precisely defined

position in the LFT – mass 6 and therefore also in the structural component, so that external loads to be carried are capable of being optimally carried and supported. The production according to the invention in the shock-cooling process is able to be proven on finished structural components, e.g., by distinguishing shaping marks on the CF – profiles, which have been created by the handling elements during the production process, by slight roundings of edges on the CF – profiles and by harmoniously balanced transitions between CF – profiles and LFT – mass.

[Para 76] In the case of the preferred crystalline thermoplastic materials, on the CF – profiles 10 in preference in the zone of a lower layer 13 (of, e.g., 0.2 – 0.4 mm thickness) below the profile surface 11 an increased crystallisation 101 is generated (refer to Fig. 7).

[Para 77] On the contact surfaces 9 between CF – profiles 10 and LFT – mass 6, in preference a directed crystallisation 102 over the contact surface is generated. This also results in improved mechanical properties and in an improved stability over time of the structural components with shock-cooled CF – profiles.

[Para 78] Light, load-bearing structural components according to the invention with integrated, shock-cooled CF – profiles are capable of being employed in a broad range of applications, e.g., in vehicle construction for components such as chassis parts, doors, seating structures, tailgates, etc. The structural components in some applications can also be constructed with solely one integrated, suitable shaped CF – profile. Two examples of structural components with one single CF – profile are illustrated in Figs. 14 und 15.

[Para 79] Fig. 14 illustrates a bumper beam support 92 with a CF – profile 10.1 integrated into the forming LFT – mass 6, which extends over the whole length. At two load receiving points L1, the bumper beam support 92 is connected with the vehicle chassis. The CF – profile 10.1 here is designed as “top-shaped”, with slanting flanks 93 and integrated into the LFT – mass, as a result of which also an energy-absorbing crash-element is



created. In another, reinforced variant, alternatively it would also be possible to integrate a second CF – profile 10.2 on a crimp underneath the CF – profile 10.1.

[Para 80] Fig. 15 illustrates an assembly support (front end) 95 with an integrated CF – profile 10.1 bent on both sides with four load receiving points L1, L2, where the assembly support is attached to the chassis. Depending on requirements, the CF – profile 10.1 may also comprise a shaping or recess at these points L1, L2, which, integrated into the LFT–mass as a crash–element 93 is plastically deformable – in analogy to the example of Fig. 14.

[Para 81] Within the scope of this description, the following designations are used:

- o 1 – Structural component
- o 1.2 – Second part (two–shell)
- o 4 – Inserts, inlays
- o 5 – CF – tapes, CF – bands
- o 6 – LFT – mass, form mass
- o 7 – Crimp
- o 8 R– ib
- o 9 – Interface, contact surface CF–LFT
- o 10 CF – profiles
- o 11 – Profile surface
- o 12 – Casing layer
- o 13 – Lower layer (layer below 11)
- o 14 – Semi–finished products store
- o 15 – Heating station
- o 16 – Chain conveyor
- o 17 – Transfer portal
- o 18 – Band gripper

- o 19 – Pre-forming elements
- o 20 – CF – profile forming station (shock cooling)
- o 21 – Profile tool
- o 21o, 21u – Upper, lower
- o 22 – CF – profile shapings
- o 23 – Profile press
- o 25 – Control of CF – profile forming station
- o 26 – Profile gripper
- o 27 – Protection gas atmosphere
- o 30 – LFT – press
- o 31 – LFT – tool
- o 31o, 31u – Upper, lower
- o 32 – LFT – shapings
- o 34 – LFT – processing, extruder
- o 35 – LFT – control of 34
- o 36 – LFT – press control
- o 37 – LFT – gripper
- o 38 – Fixing elements
- o 40 – Installation
- o 42 – Transfer robot, handling unit
- o 45 – Installation control system
- o 50 – Three-dimensional intersection point
- o 54 – Positioning points
- o 55 – Positioning shoulder
- o 56 – Thick tensile – and compressive force zones in 10

- o 57 – Thinner thrust zone
- o 58 – Lock
- o 59a, b – Axle holders
- o 60 – Belt roller, belt connection, belt lock
- o 61 – Head supports
- o 88 – Internal zone
- o 89 – External zone
- o 92 – Bumper beam support
- o 93 – Crash element
- o 95 – Assembly support, front end
- o 101 – Enhanced crystallisation
- o 102 – Directed crystallisation
- o LFT – Long fiber thermoplastic
- o CF – Continuous fiber
- o  $\alpha$  – Heat penetration coefficient
- o  $d$  – Direction vertical to the profile surface 11
- o  $\delta p$  – Thickness of the profile
- o  $\delta f$  – Thickness of the LFT – layer
- o  $Q_1$  – Heat transfer at 21
- o  $Q_2$  – Heat transfer from 6
- o  $t$  – Times, periods
- o  $t_s$  – Shock-cooling period
- o  $t_t$  – Transfer time
- o  $T$  – Temperatures
- o  $T_a$  – Surface temperature

- o  $T_i$  - Temperature inside, internal temperature
- o  $T_{wp}$  - T of CF - profile tool 21
- o  $T_{wl}$  - T of LFT - tool 31
- o  $T_f$  - T of LFT - mass
- o  $T_m$  - Melting temperature
- o  $T_{p0}$  - T of CF - tape 5
- o  $T_p$  - Input temperature of CF - profile 10
- o  $T_u$  - Lower solidification temperature
- o  $T_1, T_2$  - Profile temperature curves
- o  $DT_{kr}$  - Crystallisation temperature range
- o  $k_r$  - Crystal growth
- o  $DE_n$  - Hysteresis range (crystallisation heat, latent enthalpy)
- o  $L$  - Loads
- o  $En$  - Enthalpy
- o  $S_1, S_2, S_3, S_4$  - Process steps